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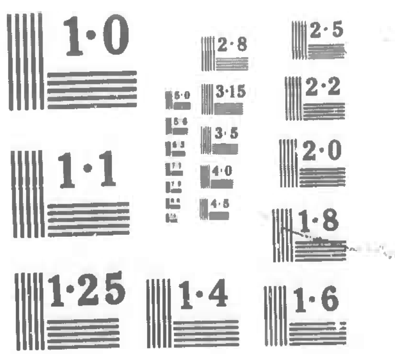

NATIONAL BUREAU OF STANDARDS
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TEXAS INSTRUMENTS
INCORPORATED
SCIENCE SERVICES DIVISION

8 September 1967

Air Force Technical Applications Center
VELA Seismological Center
Headquarters, USAF
Washington, D. C. 20333

Attention: Captain Carroll F. Lam

Subject: Fourth Quarterly Report Covering Period March 3, 1967, Through June 25, 1967

AFTAC Project No.:	VT/6707
Project Title:	Large Array Signal and Noise Analysis
ARPA Order No.:	599
Name of Contractor:	Texas Instruments Incorporated
Date of Contract:	16 May 1966
Amount of Contract:	$1, 083, 696
Contract Number:	AF 33(657)-16678
Contract Expiration Date:	25 June 1968
Program Manager:	Frank H. Binder Area Code 214 238-3473

Gentlemen:

This report covers the period through the no-cost extension of the first year's work (June 25). A one year, approximately $490, 000, extension program was approved by AFTAC, and work began under a letter contract on 26 June 1967.

Data processing for the milestones of the original contract was completed near the end of June. Below are set forth the milestones, what work was done on them, what reports will cover the milestones, and, where analysis is sufficiently complete, the principal conclusions of the studies.

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REPORT ON SUBARRAY PROCESSING

The subarray processing was completed during the last quarter and results and implications of this processing will be reported on in LASA Special Report No. 3, Subarray Processing, and LASA Special Report No. 4, Space and Time Variability of the LASA Noise Field.

Design and performance of the theoretical MCF, a comparison of the theoretical MCF with measured noise and summation processing for a few cases, and spatial and time variability of single seismometer and of velocity limited traces will be the primary topics covered by these reports.

Detailed examination of the data has not quite been completed.

DISCRIMINATION STUDY AND REPORT

A study using large-array data of the capability to discriminate between seismic energy from earthquakes and explosions was conducted. An ensemble of 38 teleseismic earthquake and explosion events recorded by the short-period LASA was analyzed. Identification parameters measuring P-coda complexity and relative spectral content were computed for the entire LASA and for subarray beam-steer outputs. Comparisons were made both on an individual event basis and statistically for various subensembles. Techniques for improving the detectability of depth phases and aftershocks, though originally developed for network application, were also examined by treating the 21 subarrays as elements of a network.

For certain source regions, certain discrimination parameters computed from the outputs of one or the other of the two subarrays examined actually showed greater separation between earthquakes and explosions than parameters computed from the large-array output. However, the large array performed better on the average over all source regions than did either subarray. Improvement with the large array was significant below a magnitude of about 4.8. This was due to the approximately 12-db improvement in signal-to-noise ratio (as compared to a single subarray) provided by the large array. Through the computation of frequency-wavenumber spectra, the large array demonstrated a very significant improvement in the ability to locate event epicenters and detect and identify as such any aftershocks. Improvement over the use of a single subarray in detecting and identifying depth phases through averaging P-30 correlations from all subarrays was also considered to be significant.

Details of this study are found in LASA Special Scientific Report No. 1, 20 April 1967, entitled A Study Of The Relative Capability Of Large And Small Seismic Arrays For Event Identification. *

Some research was conducted to optimize the technique of computing high-resolution frequency-wavenumber spectra. This research indicated that, for the detection, location and identification of P-wave energy as recorded at an array such as LASA, the following requirements should be maintained:

- Power-density spectral estimates obtained by a direct-transform method rather than a correlation method should be smoothed only after the crosspower products have been formed
- Signal-to-noise ratio used in the filter development should be in the order of 0.1 to 0.01
- The reference sensor should be on the extremity of the array
- Data gate length should include at least 50 to 60 sec of data
- Correction for travel-time anomalies should be made when using LASA data

Details of the high-resolution frequency-wavenumber research are presented in LASA Special Scientific Report No. 2, 20 April 1967, entitled Research On High-Resolution Frequency-Wavenumber Spectra. **

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* Texas Instruments Incorporated, 1967: A Study of the Relative Capability of Large and Small Seismic Arrays for Event Identification, Large-Array Signal and Noise Analysis Spec. Scientific Rpt. No. 1, Contract AF 33(657)-16678, 20 Apr.

** Texas Instruments Incorporated, 1967: Research on High-Resolution Frequency-Wavenumber Spectra, Large-Array Signal and Noise Analysis, Spec. Scientific Rpt. No. 2, Contract AF 33(657)-16678, 20 Apr.

STUDY OF SIGNAL SIMILARITY

The following three types of short-period signal similarity were analyzed:

- Single seismometers within a subarray
- Single seismometers between subarrays
- Subarray outputs

These main conclusions were reached:

- Within subarrays, waveform duplication was excellent. Variations in amplitude were sufficiently large to require amplitude equalization prior to multichannel processing. but no more sophisticated equalization technique was necessary.
- Between subarrays, waveform duplication was generally very good. Again amplitude equalization was required.
- A few subarrays had significantly different waveforms for some events. The event location appeared to determine which subarrays exhibited this anomalous behavior. A possible explanation for this effect is that crustal filtering beneath a subarray varies with event location. Short crossequalization filters appeared to equalize the anomalous waveforms adequately.
- Scattered energy does not appear to be a problem at the LASA site.
- Because of the excellent intra-subarray signal similarity, the similarity for single seismometers between subarrays was approximately the same as that for subarray outputs.

This study is detailed in LASA Special Scientific Report No. 8, Short-Period Signal Similarity At LASA.*

* Texas Instruments Incorporated, 1967: Short-Period Signal Waveform Similarity at LASA, Large-Array Signal and Noise Analysis, Spec. Scientific Rpt. No. 8, Contract AF 33(657)-16678, 1 Aug.

For the study of waveform similarity for long-period waves, four events were used. Of these four events, one was used to study the variation of P-wave amplitudes across the array. A long-period event was used to investigate the possible variation of suravce wave azimuth as a function of frequency. These main conclusions were reached:

- Waveform similarity of long-period waves of P- and S-type was excellent for the events studied.
- Long-period surface wave similarity showed the effects of dispersion.
- For the event studied for variation of P-wave amplitudes across the array, very little variation was observed. This suggests that amplitude equalization may not be needed prior to multichannel processing of long-period events.
- For the one surface wave analyzed, no variation in azimuth as a function of frequency was observed.

This study is detailed in LASA Special Scientific Report No. 9, Long-Period Signal Similarity at LASA.*

PILOT STUDY OF SUBARRAY FILTERING

This milestone formed the basis for decisions in subarray processing. Results of the completed study were outlined in LASA Quarterly Report No. 3, published 14 March 1967.

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* Texas Instruments Incorporated, 1967: Long-Period Signal Waveform Similarity at LASA, Large-Array Signal and Noise Analysis, Spec. Scientific Rpt. No. 9, Contract AF 33(657)-16678, 15 Sept.

STUDY OF LONG-PERIOD NOISE AT THE MONTANA LASA

This study analyzed nine long-period noise samples recorded between 12 November 1966 and 9 February 1967 and had as its goal the description of the salient characteristics of the long-period noise field.

The study indicated the following:

- The noise generally appears to be storm generated and is probably the result of wave activity associated with persistant North Atlantic and South Pacific lows.
- The noise field is quite time variable.
- Below about 0.05 cps (20-sec period), the noise does not behave as propagating plane waves.
- Above 0.05 cps and below 0.15 cps the noise is highly coherent. Vertical components are significantly predictable from horizontal or other vertical traces over a considerable distance (50 to 100 km).
- The coherent noise peaks in the range 0.04 to 0.15 cps appear to be strongly dominated (90 percent or more) by surface modes. There is some evidence of Love-mode noise.

Details of the long-period noise analyses will be discussed in LASA Special Report No. 12, Analysis of Long-Period Noise.

RESOLUTION OF EVENTS

Two pairs of events were composited for the resolution of events study. The first pair, Turkey ($\Delta = 83.6^{\circ}$, $Az = 35.7^{\circ}$) and Algeria ($\Delta = 86.2^{\circ}$, $Az = 35.7^{\circ}$), were separated in wavenumber by about 0.025 km^{-1} at 1 cps. The second pair, Kurile Islands ($\Delta = 60.7^{\circ}$, $Az = 313.6^{\circ}$) and Andreanoff Islands ($\Delta = 45.4^{\circ}$, $Az = 303.6^{\circ}$) were separated by about 0.01 km^{-1} at 1 cps.

For these events beam-steering was as effective as multichannel velocity filtering. Several other filtering techniques appear to offer promise.

These will be investigated for separation of long-period signals under the extension of the LASA contract.

Details of this work will be published in LASA Special Report No. 11, Resolution of Events.

FORMATION OF LIBRARY OF SHORT-PERIOD NOISE AND SIGNALS

Data reduction resulted in 13 noise samples and 14 signals. The data were about 90 percent usable. The major malady was spiking.

FORMATION OF LIBRARY OF LONG-PERIOD NOISE AND SIGNALS

The data reduction has resulted in a library of nine long-period noise samples and eight signals. In general, the data were about 60 percent usable. The most prevalent imperfections were spikes and wild traces, usually accompanied by long-period oscillations.

STUDY OF EQUALIZATION PROBLEMS

Two different studies of seismometer gain differences were conducted. A brief analysis of the coefficients used to equalize the total noise power at each seismometer was attempted. This study was intended to give an estimate of the time stability of seismometer gain differences. The results are inconclusive because the noise data gates used were too short to give good stability to the equalization numbers.

A technique for using large signals to equalize sensor outputs was evaluated. This technique equalizes the power spectra of the two events using a minimum phase operator. The technique was applied to one large event, giving moderately encouraging results.

A study of the possibility of developing regional crossequalization filters for subarray outputs was conducted using an ensemble of seven Aleutian events. The results indicate that regional equalization filters are not very effective.

A detail of the inter-array and intra-array equalization studies will be presented in LASA Special Report No. 10, Equalization Studies.

STUDY OF MANTLE P-WAVE NOISE

The mantle P-wave study has as its goals the following:

- Determination of the spatial coherence of the mantle P-wave noise
- Determination of the spatial organization and generators of the high-velocity noise
- Determination of the P-wave noise level and its fluctuations at LASA
- Detection and characterization of any discrete wavelets in the high-velocity noise field

The coherence among subarray outputs was computed for nine noise samples. Results were compared with results from various theoretical models of the P-wave noise. Indications are that the subarray outputs are generally uncorrelated beyond about 10 km and that this is considerably poorer coherence than would be expected from some probable models (storm-generated P-wave noise).

The application of a filter system designed to maximize the coherence between subarrays (group coherence) to one LASA noise sample tends to confirm that there exists no strongly coherent component in that particular noise sample. A more definitive experiment using a much longer data sample will be conducted under the contract extension.

The coherency results will be presented in LASA Special Report No. 13, Noise Coherence Among Subarrays.

Studies of the P-wave noise using the large array have not been fruitful because of the lack of coherence. A report on large-array wavenumber spectra will be published if any useful conclusions can be reached.

Estimates of the P-wave spectra at a few subarrays for 10 noise samples have been obtained using the high-resolution k-line technique. These indicate that the LASA P-wave noise level is only about 2 to 3 db below the single seismometer spectrum below 1 cps. The P-wave spectra are generally about as variable as those of the single seismometers.

These results will be detailed in LASA Special Report No. 6, Analysis of Subarray Wavenumber Spectra. This report will also contain considerable information about other dominant modes in the LASA noise field.

Various combinations of Fisher statistics and moving power spectral estimates were used to try to detect discrete arrivals in the P-wave noise. The results were negative. Model studies indicate that highly coherent P-wavelets with an amplitude of 1/2 the rms noise value should have been detected.

Results will be detailed in LASA Special Report No. 5, Detection of Discrete Arrivals In Mantle P-Wave Noise.

A STUDY AND APPLICATION OF SIGNAL DISSECTION TECHNIQUES

The problem of optimum signal extraction, when the first part of the data is noise and the last part of the data contains the time-aligned signals, is separated into two parts for computational purposes. First, the noise in the signal is estimated from the noise ahead of the signal and subtracted from the observed signal plus noise. Then optimum (least-mean-square error) signal extraction filters are designed to apply to the signal plus noise error.

A new filter is computed for each point in the signal section. The possible improvement lies only in the region of signal where the noise is predictable from the presignal noise.

Results from one noise sample indicate that using 10 channels within one subarray gives no significant improvement in mean-square-error over the time-stationary Wiener filters.

Results will be detailed in LASA Special Report No. 14, Non-time Stationary Signal Extraction.

COMPARISON OF WIENER FILTERING AND MAXIMUM-LIKELIHOOD FILTERING FOR SPECIFIC EVENTS

Two events have been processed which were previously used by SDL in a study of maximum-likelihood filtering.* The format of the SDL data would have made a careful comparison quite expensive. In view of the past work already done on this subject** only a very general comparison of the SDL results with the theoretical MLF will be made.

These results will be published in LASA Special Report No. 3, Subarray Processing. This work has not yet been completed, but no very significant conclusions can be expected.

FINANCIAL STATUS

The financial status of the contract through 30 June 1967 is summarized in Monthly Report No. 11.

Yours very truly,

TEXAS INSTRUMENTS INCORPORATED

Frank H Binder

Frank H. Binder
Program Manager

FHB:klw

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* Flinn, Hartenberger, and McCowan, 1966: Two Examples of Maximum Likelihood Filtering of LASA Seismograms, Teledyne Industries Report, 8 June.

**Texas Instruments Incorporated, 1965: A Comparison of Wiener and Maximum Likelihood Multichannel Filtering, Summer Development Rpt. by D. Jackson, 28 Oct.

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12. SPONSORING MILITARY ACTIVITY

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13. ABSTRACT

This quarterly report is a summary of the progress under LASA Evaluation, Contract No. AF 33(657)-16678, during the period 3 March through 25 June 1967.

During that period, work was completed on several milestones. The report summarizes results of the work on each milestone and gives the title and number of the special scientific reports which detail each milestone's work.

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